A HIGHLY DENSE MEMS OPTICAL SWITCH ARRAY INTEGRATED WITH PLANAR LIGHTWAVE CIRCUIT

Tomohiko Kanie, Makoto Katayama, Manabu Shiozaki, Takeo Komiya, Kazuhito Saitoh and Masayuki Nishimura

Sumitomo Electric Industries, Ltd.

1, Taya-cho, Sakaeku, Yokohama, Kanagawa, 244-8588, Japan

ABSTRACT

We propose a novel MEMS 2 x 2 optical switch array integrated with Planar Lightwave Circuit(PLC) for application to Optical Add Drop Multiplexes(OADM) in Wavelength Division Multiplexed(WDM) transmission systems. This switch array consists of two chip connected together by flip chip bonding. One is the MEMS device which has 16 channel latched silicon actuators with micro-mirrors, and the other is a PLC which has a 16 channel 2 x 2 cross type waveguide array. In order to achieve highly dense integration, the MEMS actuator has a long beam cantilever arranged with a 500 µm period.

INTRODUCTION

Recently, large increases in the WDM channel count, and new optical components in networks have all led to increased demand for compact, multichannel, integrated devices. The MEMS technology has been proposed for these requirements. The use of MEMS-based free-space fiber optic switches is the leading proposed solution for large-matrix, all-optical switch fabrics in long-haul networks [1-3]. While in the metropolitan networks, a large number of small-port-count devices were required. The MEMS 1 x 2 and 2 x 2 switches have advantages in term of cost, size, and power consumption for these requirements.

Several optical MEMS switches have been proposed for integration with aligned optical fibers [5-7]. In these switches, a micro-mirror with a comb drive actuator was arranged at the cross point of aligned optical fibers. A millimeter order area was needed for each channel, because of the large diameter and the inflexible placement of the optical fibers and the large sized comb drive. We have developed an optical switch array that combines a highly dense MEMS device with a PLC, which was flexibility in the placement of the waveguide. This paper reports a newly-developed compact 16 channel MEMS switch array which has novel actuator combined cantilever beams with comb drive arranged with a 500 µm period.

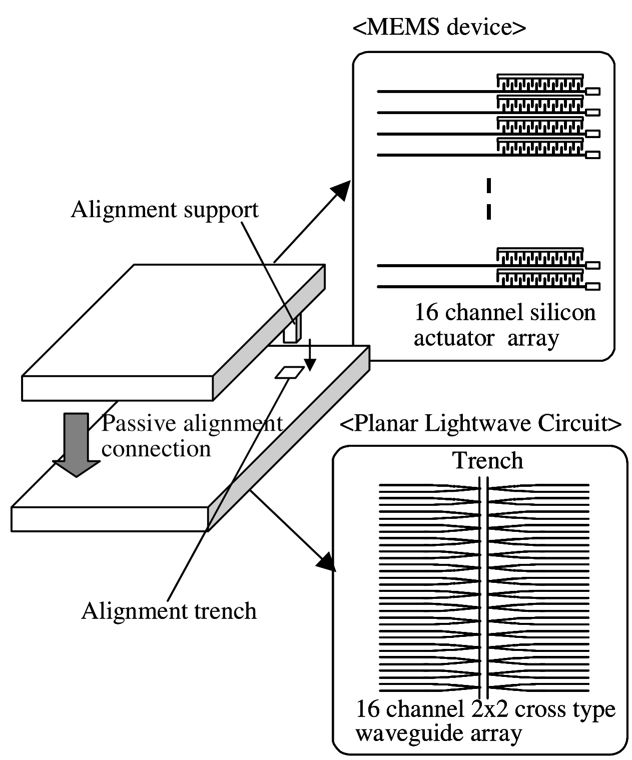
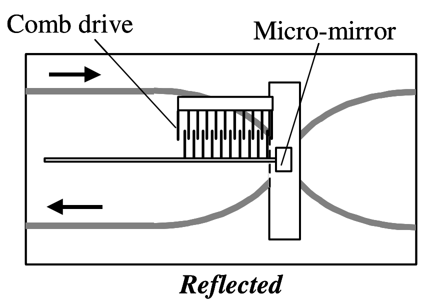


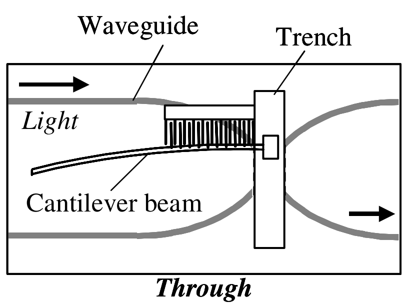
Figure 1. Schematics of optical switch combining the MEMS device with PLC.

DESIGN AND FABRICATION

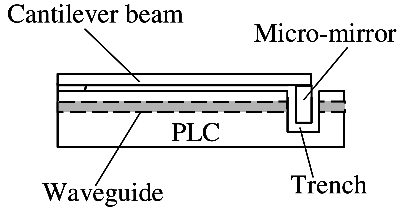
For multichannel switch array, a highly dense MEMS device and PLC were combined in order to minimize the overall size. Figure 1 shows the schematic concept of the optical switch array, which consists of two parts fabricated separately and connected together by flip-chip bonding. The MEMS device has silicon actuators with micro-mirrors, latching systems and alignment supports, while the PLC has 16 channel 2x2 cross type waveguides and alignment trenches. By passively connecting these devices together utilizing the alignment structures, the micro-mirror on the tip of the actuator is inserted into the trench, precisely. The sizes of the whole 16 channel switch array are 20mm x 14mm x 0.15mm.



(a) Parallel state(Top view)



(b) Cross state(Top view)



(c) Side view

Figure 2. Movement of the optical switch

Figure 2 shows top views and a side view of the one channel 2x2 switch. In the parallel state the light from the waveguide is reflected by the micro-mirror (Fig.2(a)). When a voltage is applied to the comb drive to operate the switch, the cantilever beam is moved parallel to the PLC and the micro-mirror moved along the trench. The micro-mirror is moved out of the cross point to the cross state (Fig.2(b)) and the light is passed through the trench.

The size of micro-mirror is 45 μm(L) x 30 μm(W) x 50 μm(H). The movement of the micro-mirror required for switching was about 50 μm. The driving voltage and speed is strongly dependent on the beam length and thickness. Producing a displacement 50μm while maintaining a reasonable driving voltage suggests that the cantilever beam must be extremely flexible. On the other hand, higher resonant frequency is desired for faster switching speed. Shorter and wider beams are preferable for high resonant frequency. Therefore, there are trade-offs between beam width and length to obtain both high response of actuator and large displacement for the micro-mirror. It is designed that the resonant frequency of this actuator is maintained > 1kHz. Combining a long cantilever beam with an electrostatic comb drive actuator was expected to realize such a large movement. The cantilever beam was flexible enough to bend with weak force, while the response and the comb drive supplied sufficient force. Furthermore, larger electrostatic force is obtained by tiling both parallel plate

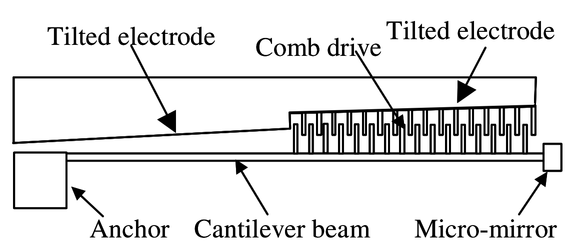


Figure 3. The detail of the actuator

electrode and bottom of comb electrode, shown in Fig.3, so that when the actuator move, both electrodes are closer not to contact together. The cantilever beam length, width and thickness were 2.9 mm, 10 µm and 50 µm.

This switch includes a latching mechanism consisting of a silicon actuator similar to the micro-mirror's.

By filling the trench and the actuators with index-matching fluid, the insertion loss and the backreflection were decreased and the mechanical damping was adjusted. The waveguide was designed to have an insertion loss of 0.9 dB with the alignment tolerance of about 10 µm between the PLC and the MEMS device and it had an asymmetric pattern to suppress the crosstalk less than -50 dB.

The MEMS devices were fabricated by Deep Reactive Ion Etching (DRIE) of a Silicon-On-Insulator(SOI) wafer. The micro-mirrors were fabricated using micromachining technology of high aspect ration structures. Figure 4 shows a scanning electron microscope image of the MEMS device arranged with a 500 µm period.

The PLC was fabricated by the deposition of SiO2 on a silicon wafer and the RIE process. The trench in PLC which micro-mirrors and alignment supports insert were fabricated by DRIE of SiO2.

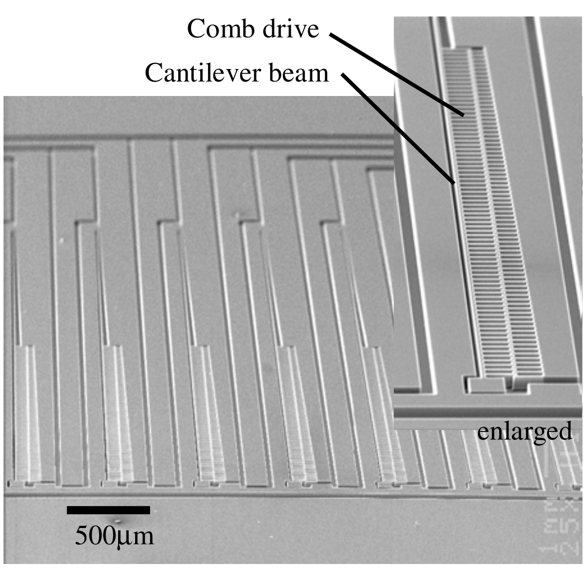


Figure 4. SEM image of the MEMS device

PERFORMANCES

The fundamental characteristics of the switch were measured. To evaluate the driving voltage, the DC voltage was slowly increased until the pull-in. The results are shown in Fig. 5. The pull-in voltage is about 24 V which is equivalent to the design voltage of 23 V.. The insertion loss was equivalent to the design value and the crosstalk was below 30 dB in the cross state.

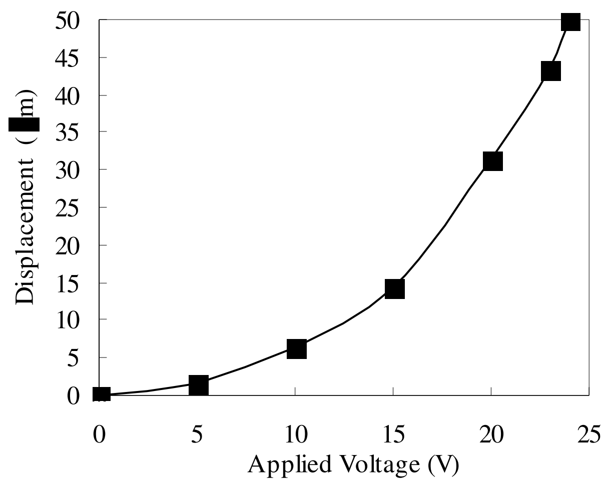


Figure 5. Measurement mirror displacement as a function of applied DC voltage.

CONCLUSION

We reported a novel compact 16 channel MEMS switch array which has novel actuator combined cantilever beams with comb drive arranged with a 500µm period. The comb drive and long cantilever were combined to demonstrated a low voltage and large mirror displacement actuation. The insertion losses for single mode fibers was enough to optical networks. The multichannel structure and the compactness of the novel optical switch array are highly attractive for the WDM networks.

REFERENCES

[1] C. A. Brackett, A. S. Acampora, J. Sweitzer, G. Tangonan, M. T. Smith, W. Lennon, K-C Wang, and R. H. Hobbs, “A scalable multiwavelength multihop optical network: a proposal for research on All-Optical networks,” Journal of Lightwave Technology, Vol. 11, pp.736-753, 1993.

[2] L.Y. Lin, E. L. Goldstein, R. W. Tkach, “Free-Space Micromachined Optical Switches for Optical Networking,” IEEE Journal of Selected Topic in Quantum Electronics, Vol. 5, pp. 4-9, 1999.

[3] S. S. Lee, L. S. Haung, C. J. Kim and M. C. Wu, “Free-Space Fiber-Optic Switches Based on MEMS Vertical Torsion Mirrors,” Journal of Lightwave Technology, Vol. 17, pp. 7-14, 1999.

[4] C. Marxer, C. Thio, M. A. Gretillat, N. F. de Rooij, R.Batting, O. Anthamatten, B. Valk, and P. Vogel, “Vertical Mirrors Fabricated by Deep Reactive Ion Etching for Fiber-Optic Switching Applications,” Journal of Microelectromechanical System, Vol. 6, pp. 277-285, 1997.

[5] Daisuke Miyauchi, Hiroshi Toshiyoshi, and Hiroyuki Fujita, “ Optical Cross-connect Switch by Silicon Micromachining,” MOEMS ’97, pp.253-258.

[6] A. A. Yasseen, J. Mitchell, T. Streit, D. A. Smith, and M. Mehregany, “A Rotary Electrostatic Micromotor 1x8 Optical Switch,” MEMS’98, pp.116-120.

[7] W. H. Juan and S. W. Pang, “Batch-Micromachined, High Aspect Ratio Si Mirror Arrays for Optical Switching Applications,” Transducers ’97,pp.93-96.